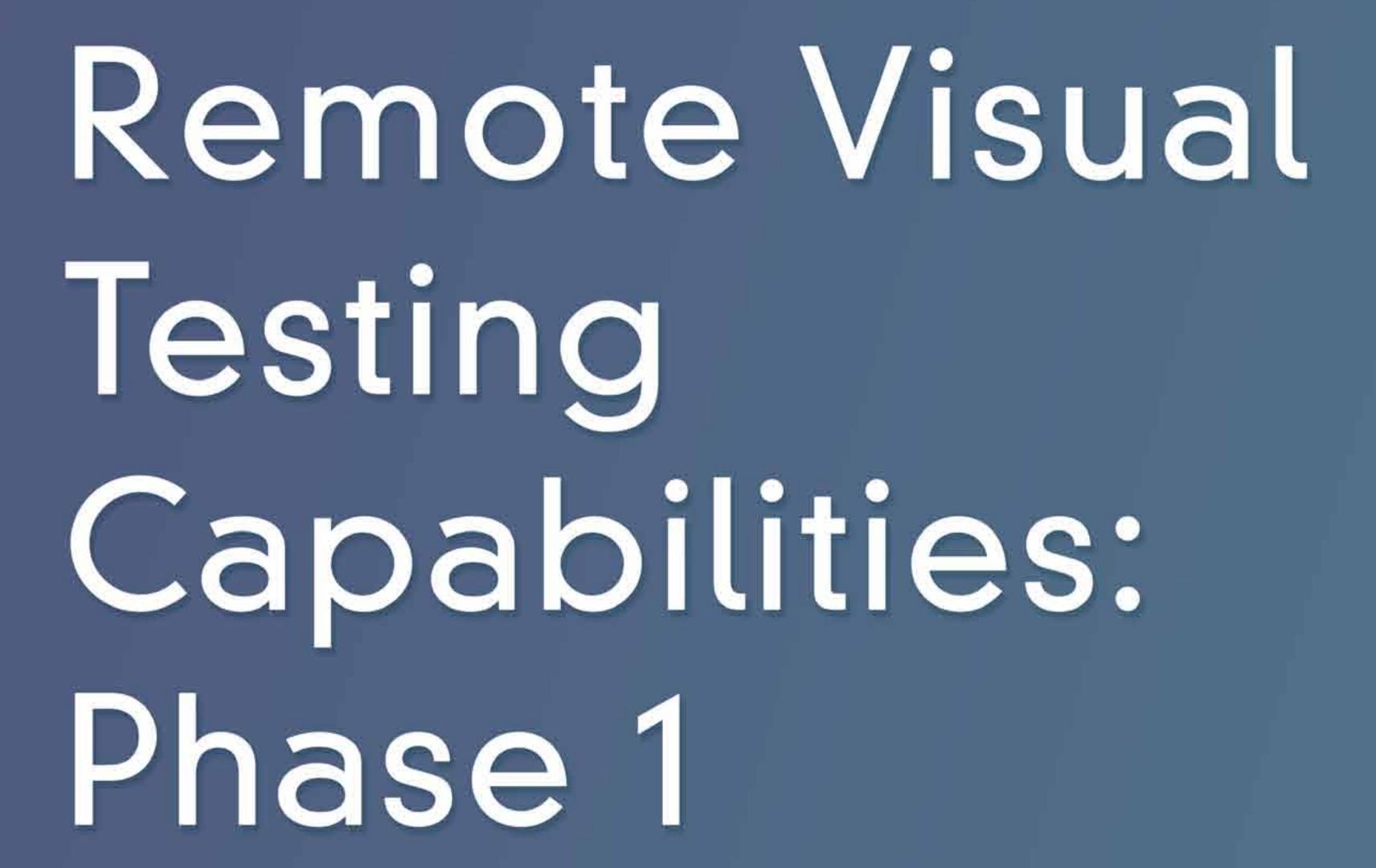


## PT 2011



Office of Nuclear Regulatory Research

### Introduction

As technology improves and as the use of visual testing (VT) to detect small flaws and cracks expands (referred to as enhanced VT-1 examinations [American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) Section XI], the industry and the U.S. Nuclear Regulatory Commission (NRC) are interested in establishing the capabilities and limitations of performing remote camera-based VT-1 examinations.

The NRC and Pacific Northwest National Laboratory, in cooperation with the Electric Power Research Institute under a Memorandum of Understanding Addendum, conducted a preliminary visual round robin test (Phase 1) on a series of samples designed to assess the factors impacting the reliability of remote VT and gather information to support the design and performance of a robust Phase 2 visual round robin

### Motivation

Visual examination of reactor internals is required by ASME Code Section XI for beltline components. Utilities operating boiling water reactors commonly perform additional visual examinations in addition to those required by Section XI for a wide range of reactor vessel internal components.

Visual examinations for these locations can be challenging because the reactor internals are highly irradiated and the exams are conducted using underwater closed-circuit television cameras (CCTVs). The imaging, lighting, and display technologies behind CCTVs have changed dramatically over the past 10 years. For example, CCTV systems in the United States have at best 486 vertical scan lines, while newer radiation-hardened digital systems have resolutions up to 720 vertical scan lines.

Imaging technology has improved from the cathode-ray television screens to modern high-resolution flat-screen monitors. Incandescent spot-lights are being replaced by "light-emitting diode (LED)" ring lights and other lighting systems.

## Previous Work

Earlier studies on remote visual testing had determined the following:

Cracks with a crack opening displacement (COD) of less than 20 µm were not reliably detectable

Cracks with a COD of greater than 100 µm were reliably detectable

The reliability of detecting cracks with CODs between 20 and 100 µm was highly reliant on the inspection conditions and the skill of the inspectors

### Phase I Round-Robin Tests

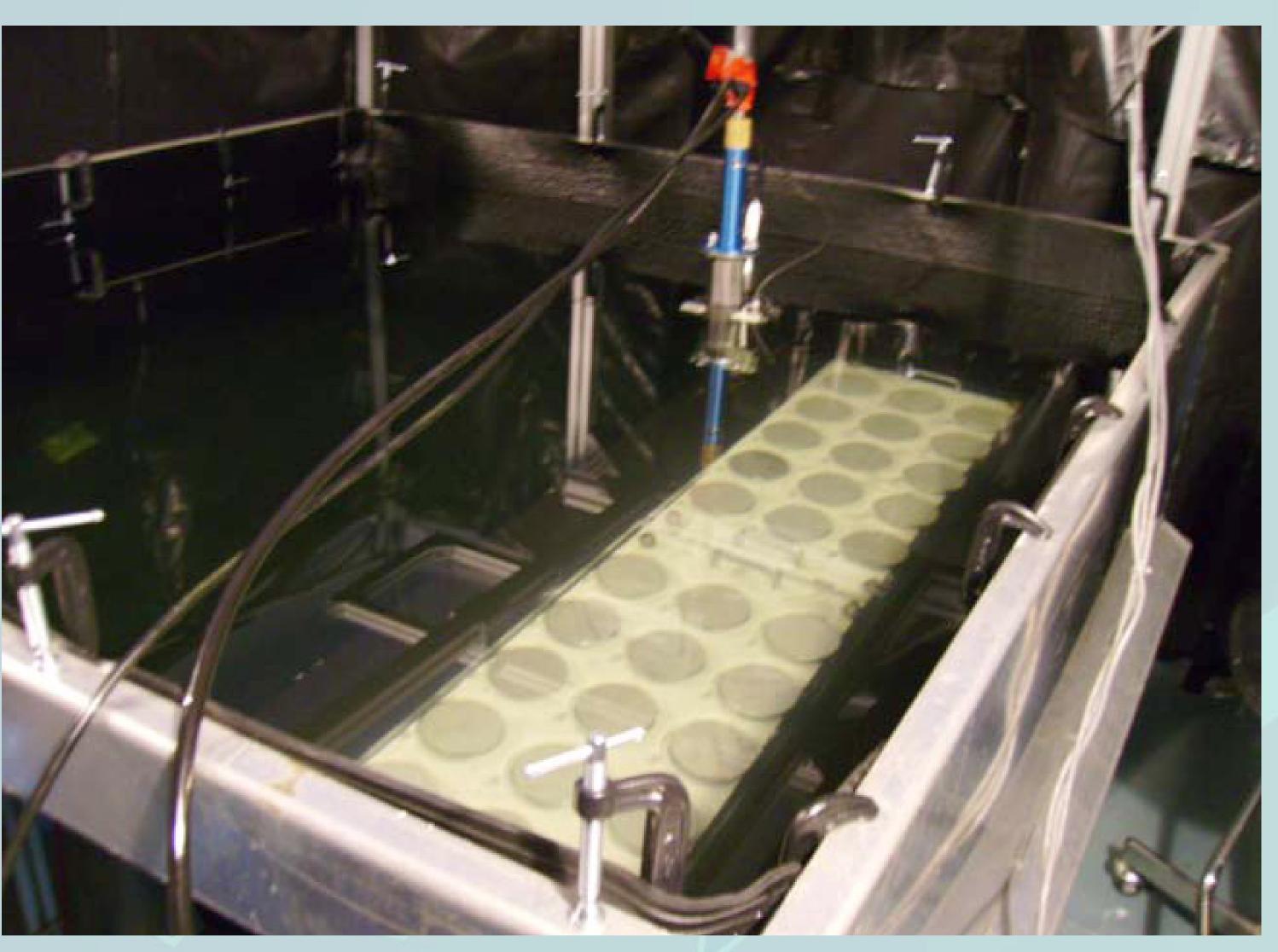
The visual round robin tests were designed to, among other things, assess the detection rates of tight cracks using remote video cameras. A series of 60 test samples with 28 implanted cracks were built to provide a wide range of CODs, ranging from very small (less than 10  $\mu$ m) to relatively easy to detect (greater than 100  $\mu$ m). The samples consisted of three-inch-diameter stainless steel circles with fatigue cracks on their surfaces.

Three inspection companies using 10 different camera systems were tested. The inspection teams ranged from professional inspectors with Level III VT-1 certification and years of experience inspecting nuclear power plants to camera vendors with little formal experience or training. The cameras ranged from simple black-and-white tube cameras to modern high-definition digital systems and included various lighting systems.

The Phase 1 tests were designed to assess the maximum capabilities of the video cameras under controlled conditions and provide valuable information for designing the Phase 2 Round-Robin test.

# Blank Sample Cracked Sample Crack Orientation Mark

The test samples were three-inch-diameter as-rolled stainless steel discs. Twenty-eight of the disks had a mechanical fatigue flaw implanted at the testing surface. Another 32 samples were left as blanks with no cracks.



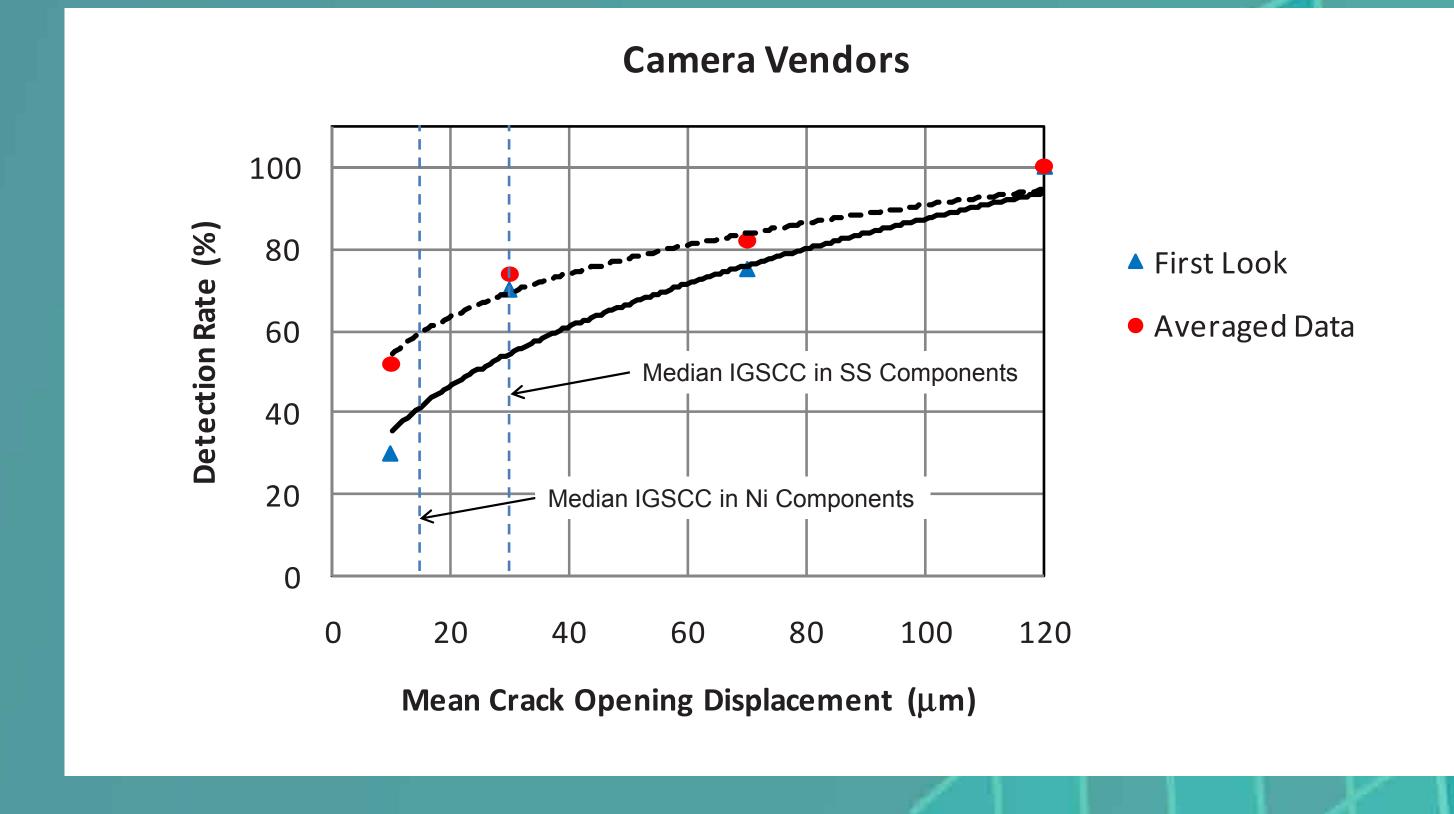
The test samples were placed in holders and set in a tank of water for testing. The samples were placed in the holders in random order and in random orientations.

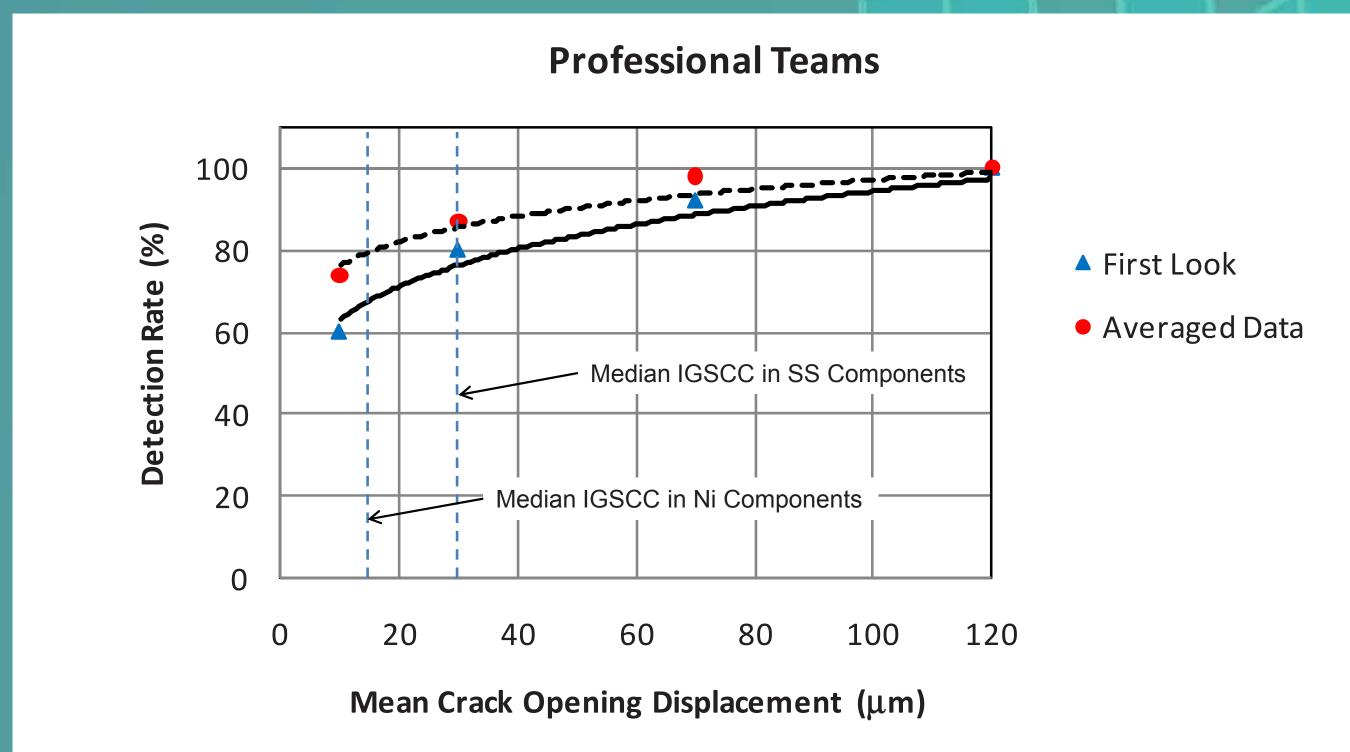
### **Test Results**

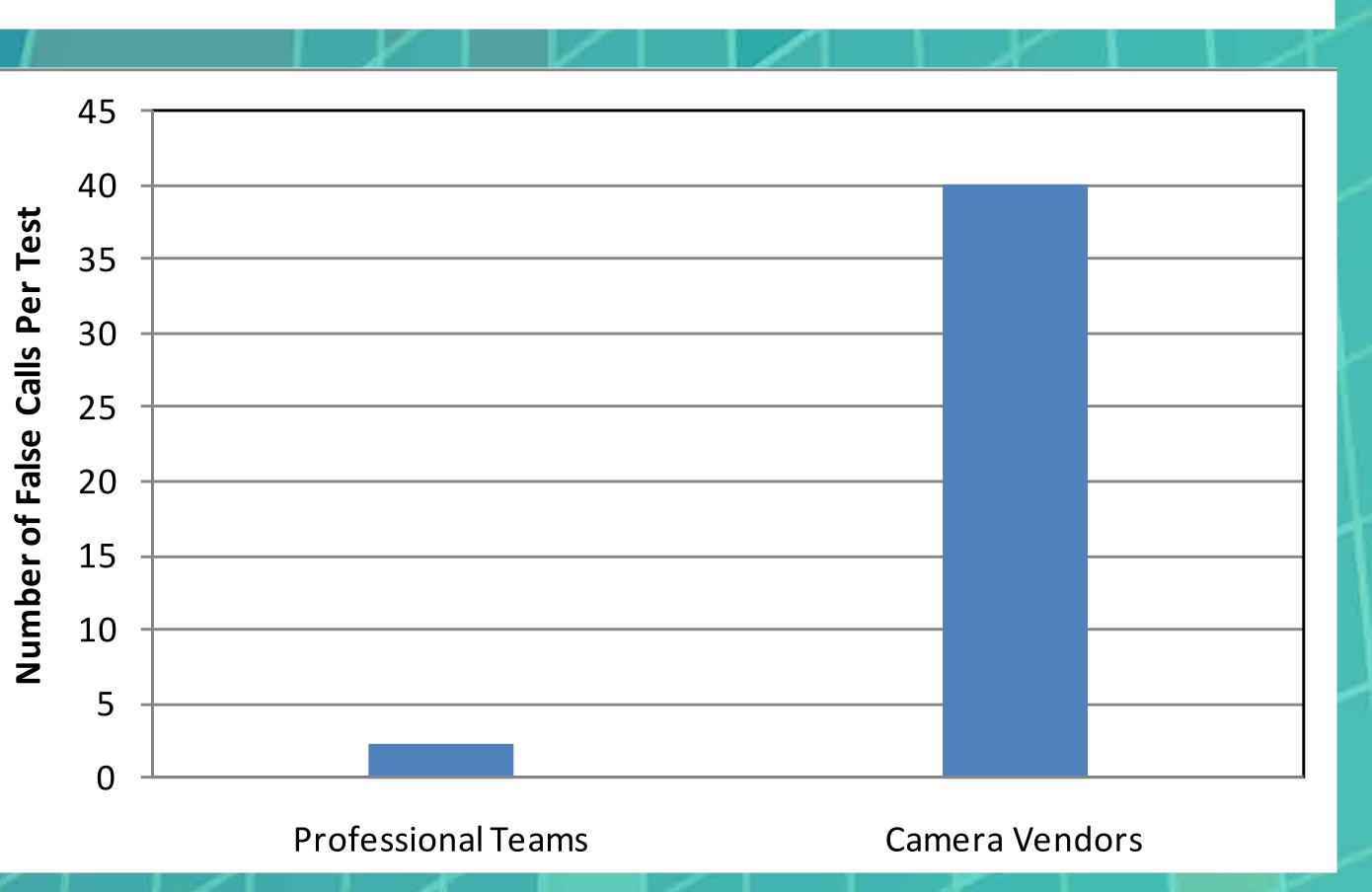
Phase 1 test results showed higher than expected detection rates based on previous work and literature. The higher detection rates appear to be the result of improvements in camera technology and the conditions under which the tests were taken (nearly ideal laboratory).

A review of the recorded data showed that all cameras used in the tests were able to image even the tightest cracks.

The results showed that additional analysis is required relative to COD. Defining a single COD to represent a crack of varying width may be insufficient.





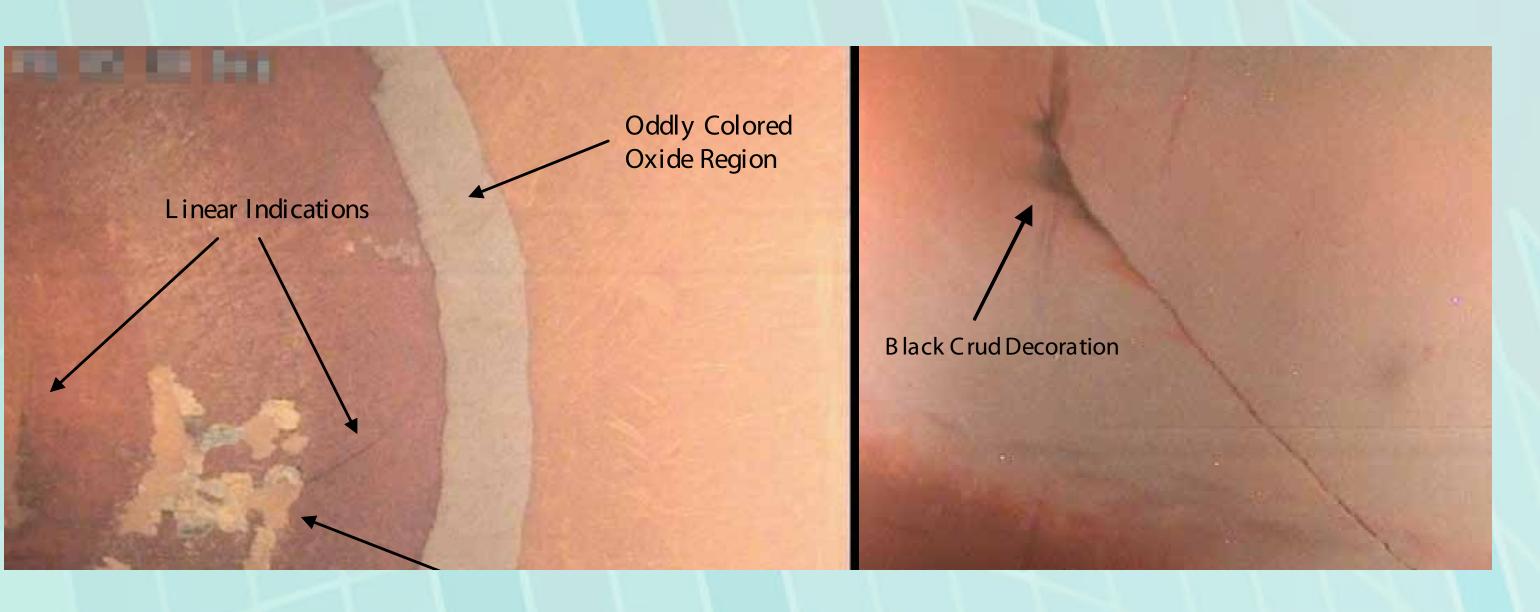


### How Realistic Are the Phase I Tests?

The Phase 1 tests presented the inspectors with nearly ideal inspection conditions.

Cracks in vessel internals can be covered by deposits. In addition, radiation fields can affect image quality, and moving water can affect camera positioning.

The conditions under which Phase 1 was conducted were found to be appropriate for assessing many of the factors impacting the reliability of remote VT.





Realistic surfaces present challenges not included in the Phase I tests.

### Path Forward—Phase 2 Tests

Phase 2 testing is tentatively scheduled to for the summer of 2012. The results of Phase 1 will be used to make Phase 2 testing more realistic and to ensure that Phase 2 is properly designed to adequately investigate the important parameters.

A novel surface crack simulation method has been developed using a laser to cut a crack onto the surface of a sample. Complex crack morphologies can be "printed" onto the sample with controlled COD and location.

Phase 2 will address some important lessons learned from Phase 1. The limited specimen set, one crack per specimen, and grading unit scheme resulted in a "training effect," where trained examiners started to recognize specimens after repeated viewings and detection of smaller cracks improved during the tests.